VAN PETTEN

Experiments
on
Concrete for Furnace Lining

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EXPERIMENTS
ON
CONCRETE FOR FURNACE LINING

BY

ALBERT ALEXANDER VAN PETTEN

THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ALBERT ALEXANDER VAN PETTEN

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering

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EXPERIMENTS ON CONCRETE FOR FURNACE LINING.

In connection with some construction work being done at Guanica, Porto Rico, the Guanica Centrale, a sugar making company, installed a number of new boilers. The scarcity of native masons, who are poor workmen at best, and the very slow rate at which they worked, caused the men in charge to look about for some method of getting along without masons. If fire-brick were to be used, they must be laid by masons; therefore in order to do away with the masons, it was necessary to use some other material in place of fire-brick.

Concrete that could withstand the heat to which a boiler furnace is subjected, would certainly take their place. But could such a concrete be made? It was decided to make a test. As an experiment, the arch over the feed door of the furnace was made of a concrete composed of 1 part Atlas cement, 2 parts sand, and 5 parts fire-brick broken to pass through a 2-inch ring. The arch was 8 inches deep at the crown, had a width equal to the length of a fire-brick, and extended 8 inches on either side of the opening for the feed door, thus taking the place of about fifteen fire-bricks. This concrete was put in under the direction of the writer about the first of December. From December 20 until the middle of March, this furnace was in constant operation. At the latter date, the furnace was to be rebuilt, and the front wall including the experimental arch was taken out. It came out in one solid piece and appeared to be in perfect condition.

On account of this experience, the writer determined as his

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thesis subject to make a number of tests to ascertain, if possible, whether it is practical to use concrete for the entire lining in a furnace or in any place where exceedingly high temperatures must be withstood. The princip~~le~~al engineering literature on concrete and fire-proofing was carefully examined; but no record was found of tests on concrete at furnace temperatures for more than a few hours duration. Accounts are given of tests made in New York with the different kinds of fire-proof concrete, in which concrete made of 1 part cement, 2 parts sand, and 5 parts cinders stood an average temperature of 2,000° F., with a maximum of 2,300° F., for four hours without showing any bad effects. However, this test does not prove that this kind of concrete will stand such high temperatures for an indefinite length of time.

The writer sent letters of inquiry to nine prominent manufacturers of cement and received replies from all. These answers show that the manufacturers do not know of any concrete mixture that will withstand furnace temperatures and also that they do not know of any experiments having been made to determine if such a concrete could be made. No information of any value was received from this source, although one manufacturer did suggest that experiments might be made using ground fire-brick and cement.

Since so little is written in regard to the fire-resisting qualities of concrete, it became necessary to look into the subject almost entirely from the experimental side by testing concrete made of different materials and in varying proportions.

For the purpose of tests, 6-inch cubes were made of the following compositions in varying proportions; cement, sand or fire-clay, and broken fire-brick; cement, sand or fire-clay, and ashes; cement,

sand or fire-clay, and trap-rock; and cement, sand or fire-clay, and limestone. Atlas Portland cement was used in all cases, and the trap-rock came from New Jersey.

In order to subject the cubes to the greatest possible heat and also to the gases produced from the fuel in an actual furnace, the cubes were placed on the bridge wall of the furnace in Boiler No. 3, University of Illinois Heating Plant, where the heat averaged about 2,300° F. Danville coal is used in this boiler.

TABLE 1.

Results of Subjecting Cubes to the Heat and Gases on the Fire Wall of a Furnace.

Ref. No.	Composition of Mixture.	Date of Making.	Beginning of Test.	Age, Days.	Duration of Test. Days.	Results.
			Cubes Set in Air.			
1	1 cement 2 fire-clay 6 fire-brk.	Nov. 21	Jan. 30	70	26	In excellent condition.
2	1 cement 2 fire-clay 8 fire-brk.	Nov. 21	Jan. 30	70	16	Disintegrated.
3	1 cement 2 fire-clay 4 fire-brk.	Nov. 21	Jan. 30	70	26	In excellent condition.
4	1 cement 1 fire-clay 6 cinders	Nov. 28	Jan. 30	63	2	Disintegrated.
5	1 cement 2 sand 5 cinders	Nov. 28	Feb. 14	78	1	Disintegrated.
6	1 cement 1 fire clay 6 cinders	Nov. 28	Feb. 14	78	3	Disintegrated.
7	1 cement 2 sand 5 trap	Feb. 1	April 2	60	4	Disintegrated.
8	1 cement 2 fire-clay 5 trap	Feb. 1	April 2	60	21	In good condition.
9	1 cement 2 sand 5 l. stone	Feb. 1	April 2	60	2	Disintegrated.
10	1 cement 2 fire-clay 5 l, stone	Feb. 1	April 2	60	7	Disintegrated.

TABLE 1 (continued)

Ref. No.	Composition of Mixture.	Date of Making.	Beginning of Test.	Age, Days.	Duration of Test. Days.	Results.
11	1 cement 0.1 salt 2 fire-clay 5 trap	Feb. 1	April 23	81	4	Disintegrated.
12	1 cement 0.1 salt 2 fire-clay 5 l.stone	Feb. 1	April 23	81	4	Disintegrated.
13	1 cement 2 fire-clay 6 fire-brk.	Nov. 21	April 27	157	25	In good condition.
14	1 cement 2 fire-clay 4 fire-brk.	Nov. 28	April 27	149	25	In good condition.
15	1 cement 2 fire-clay 5 trap	Feb. 1	April 27	85	9	Disintegrated.
16	1 cement 1 fire-clay 6 cinders	Nov. 21	Mar. 6	103	3	Disintegrated.
17	1 cement 2 fire-clay 8 fire-brk.	Nov. 21	Feb. 25	94	6	Disintegrated.
18	1 cement 0.1 salt 2 fire-clay 5 fire-brk.	Dec. 1	Feb. 25	86	7	In good condition.
19	1 cement 2 sand 6 fire-brk.	Nov. 21	May 22	183	4	Disintegrated.
	Cubes Set in Water.					
20	1 cement 2 fire-clay 6 fire-brk.	Nov. 21	April 27	157	25	In fair condition.
21	1 cement 2 sand 4 fire-brk.	Dec. 1	Mar. 6	103	4	Disintegrated.

Most of the specimens were allowed to set in air under the same conditions that a furnace lining would be allowed to set, but for the purpose of experiment two specimens were allowed to set in water, a condition that is out of the question for a furnace lining. However, the specimens that set in water showed no greater heat resisting qualities than do the specimens that set in air.

The time that the specimens were allowed to stand before testing is much longer than would ever be given a furnace lining in actual practice. On the other hand, a slow fire can be built in a furnace after the lining has set for a reasonable length of time, say 12 or 15 days, and dry the concrete almost as well as if it had been allowed to stand as long as the specimens. Care must be taken during the drying of the furnace lining not to create sufficent heat to drive off the water from the concrete in the form of steam. It must also be remembered that a new furnace lining is gradually heated from the temperature of the open air to the furnace temper--ature, while the specimens were passed immediately from the ordinary air temperature to the furnace temperature. Any advantage that the specimens might have over an actual furnace lining due to the longer time of setting is probably more than counterbalanced by the severe test of passing the specimen immediately from the open air into the hot furnace.

From the results of the experiments, it is seen that the only specimens which withstood the high temperatures are those made of cement, fire-clay, and fire-brick, excepting No. 8 in which trap--rock is used instead of fire-brick.

We know positively that either fire-brick or fire-clay are perfectly able to withstand the temperatures at which the tests

were made; and we also know that fire-brick laid in fire-clay, the present method of constructing furnace linings, do withstand furnace temperatures. From these facts, it is to be expected that a concrete made of fire-brick, fire-clay, and cement will withstand the same intensity of heat. However, a concrete of cement, fire-clay, and fire-brick in order to withstand furnace temperatures must have the materials so proportioned that the concrete is free from air holes or voids. The results for different proportioning of the materials is readily seen by comparing the actions of specimens No. 1, 3, 13, and 14 with No. 2 and 17. The mixture in the four former specimens is such that the concrete contained no voids or air holes, but was one solid mass. In the two latter specimens the mixture is so lean that the voids in the broken brick were not entirely filled by the cement and fire-clay even after hard tamping, which accounts for the disintegration of these specimens, although it must be noticed that specimen No. 2 resisted the heat sixteen days and No. 17 six days. The heat causes the air in the voids and air holes to expand, and the expanding air in working its way out of the specimen tends to break apart the concrete; but this effect of the expanded air is much more severe with lean than with rich concrete, because of the greater number and size of the voids and because of the weaker concrete. The faces of the specimen having a number of small air holes, give the flames a chance to work their way into the specimen, while the faces of a specimen containing no voids deflect the flames.

A study of Table 1 shows that in some specimens a concrete containing trap-rock possesses fire resisting qualities quite equal to a concrete containing fire-brick -- see No. 8, Table 1. However,

all specimens containing trap-rock do not show the same uniformity that is shown by specimens containing fire-brick -- see No. 11 and 15, Table 1. No reason can be given for the lack of uniformity exhibited by the specimens containing trap-rock.

The fact that sand can not possibly be used is very evident, since in all cases where sand was used, the specimen disintegrated within a very short time, four days being the longest time any specimen with sand in its composition withstood the heat -- see No. 7, Table 1. This effect is accounted for by the fact that sand melts at high temperatures.

A composition of cement, sand, and ashes such as proved highly satisfactory in the tests made in New York to determine the heat resisting qualities of concrete for fire-proof buildings, is a complete failure when subjected to a furnace temperature for several days. The difference in the action in the two cases is probably partly due to the fact that in the former case the test continued only four hours while in the latter it continued several days; and also partly to the corroding influence of the furnace gases in the latter experiments. The substitution of fire-clay for the sand makes no very marked difference in the ability of the concrete to withstand heat as is seen by comparing No. 4 and 6 with No. 5. All the specimens containing cinders disintegrate gradually from the outside towards the center crumbling off in the form of powder, so it is only a question of time until the entire mass will crumble away. Three days was the longest time required to entirely disintegrate any specimen containing cinders.

The use of limestone for furnace linings is unreasonable. However, tests were made to prove conclusively that such a compos-

-ition will not stand furnace temperatures. The heat changes the limestone to lime by driving off the CO_2 which action breaks up the concrete -- see No. 9 and 10, Table 1.

Thus far we have studied the effect of the various constituents of the concrete; but now it is proposed to determine, if possible, that concrete which best withstood the action of the high temperatures. A study of the condition of specimens No. 1, 3, 8, 13, 14, 18, and 20 shows No. 18 to be much the best. No. 14 is in a very solid condition, as are also No. 1, 3, and 8; the only difference between these and No. 18 being that the edges of the latter are still sharp, while the edges of the former are slightly corroded. No. 13 appeared quite solid, but when struck several sharp blows with a hammer, it readily broke to pieces, showing it to be a poor composition to withstand furnace temperatures. No. 20 was still poorer than No. 13, several cracks appearing in the specimen after cooling, and one blow of the hammer being sufficent to break it all to pieces.

Through the knowledge gained from the experiments, it may be stated that the use of concrete for furnace linings or any place where high temperatures must be withstood is possible and practical. A concrete made of the proper proportions of cement, fire-clay, and fire-brick proved to be able to withstand the furnace temperatures and injurious gases for as long a time as the concrete was subjected to them; also in one case out of two tests, a concrete made of cement, fire-clay, and trap-rock withstood the furnace temperatures and gases. These facts lead to the conclusion that concrete made of any materials which in themselves are not disintegrated by the most intense heat of a furnace can be used for furnace linings when

the materials are so proportioned that the concrete is practically free from voids and air holes.

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